

# **Continual Non-Condensable Gas Removal Testing – Performance and Lessons Learned**

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# Continual Non-Condensable Gas Removal Testing— Performance and Lessons Learned

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## Keywords

*Binary plant, condenser efficiency, non-condensable gas removal*

## ABSTRACT

The operating experience and plant benefit analysis of a membrane-based continuous non-condensable gas (NCG) removal system is discussed. Results from testing at the Mammoth Pacific (Ormat) geothermal plant provide the basis for the benefit analysis.

## Introduction

Our reports in the past have focused on the design and operating principles of the membrane-based noncondensable gas (NCG) removal system. We have also reported results from tests performed at Steamboat (Reno, NV) and Mammoth Pacific (Mammoth Lakes, CA). However, the unit had operated only sporadically, being easily upset by changing ambient conditions and periods of high liquid carryover from the plant condenser. Previously, improved operation was sought through minor control and hardware modifications, but these proved insufficient to assure reliable operation. Our work in the last year has focused on hardware changes intended to lead to reliable and continuous unattended operation. In addition, we are now gathering data that can be used to quantify the benefit of a continual low fraction of NCGs in the plant condenser. The remainder of this report will address these recent efforts.

## Membrane Performance

**Length of membrane service:** The membranes were first used in Spring 2002 after installation at the Steamboat plant in Reno, NV. On two occasions, they were removed from their housings and inspected – no evidence of wear or failure was noted. In addition, testing at Reno and, subsequently,

Mammoth Pacific (Mammoth Lakes, CA) showed no detectable degradation of performance with time. The current separation (membrane) performance at Mammoth has not changed noticeably from startup, approximately 2 years ago. Thus, the membranes have been in use for over 3 years. The membrane manufacturer (Membrane Technology and Research, Inc. of Menlo Park, CA) uses the same membranes for other organic/air separations and typically warrants them for 5 years service. Based on experience with this skid, there is no reason to doubt that the membranes will last at least this long.

**Range of air removal rates:** The unit was originally specified to have an air removal rate in excess of 20-30 gm/hr, a range determined by the growth rate of NCG partial pressure in the two plants studied for NCG system application. However, the minimum size of applicable compressors and the surface areas of commercial membrane modules dictated that the unit be considerably oversized for this specification. Testing at Steamboat was performed at an average air-removal rate near that of the original specification. However, the rate at which air is introduced into the binary side of the plant at Mammoth is well in excess of the specification. At Steamboat, air exhaust rates of 100-300ml/min (intermittent) were observed once the unit reached equilibration with air entering the system. At Mammoth, continual air removal rates in excess of 14 l/min (over 40 times the design removal rate) have been observed. As is typical of membrane separations, high throughputs are accompanied by decreased separation. At Steamboat, the low vent rate (i.e., low throughput) resulted in less than 1% working fluid in the vented air. At Mammoth, vent rates over 10l/min were typically accompanied by 5% to 7% working fluid in the vented air. It should be noted that the membrane intrinsic performance is slightly better for isopentane (Steamboat) than for isobutane (Mammoth), as isopentane is more easily condensed and penetrates the membranes more readily. This undoubtedly accounts for some of the difference in performance noted between system at the two plants. However, the throughput rate is the principle factor in explaining this difference.

## Skid Reliability

**Continual Operation:** Continual unattended operation was targeted in skid design, but proved difficult to achieve. During normal operation, the unit shut down frequently (i.e., several times per day) resulting from failure to drain the knock-out vessels within the allotted time. This appeared to be due to two causes: occasional rapid intake of liquid working fluid from the condenser and failure of the liquid return pump to operate correctly. In addition, the unit shut down very quickly at Mammoth during periods of subfreezing temperatures. The first attempts to alleviate this problem focused on three possible methods to improve performance:

- Adjusting the KO drum drain control valves to drain more rapidly,
- Adjusting the unit inlet pressure to only slightly below the condenser pressure. This was not an acceptable long-term fix, as varying ambient temperature, hence condenser pressure, required frequent readjustment.
- Lengthening the time allotted for the KO drums to drain.

While these changes did improve somewhat the performance of the unit, they did not lead to continual operation. The best operation achieved at Steamboat still suffered from shutdowns on a near-daily frequency. When the unit was moved to Mammoth, interruptions occurred more frequently. In sub-freezing temperatures, extended operation could not be achieved, with shutdowns occurring approximately hourly. The shutdowns at Mammoth were attributed to two causes – water in the binary system and unreliable liquid return pump operation. Unreliable pump operation was suspected earlier at Steamboat, but never proven, as cavitation due to inlet conditions was also possible. The manner in which these problems were addressed is discussed in the next section.

**Modifications:** The difficulty in returning condensed working fluid to the condenser was considered the most seri-

ous operating problem with the unit. As a result, a major modification, involving installation of a new vessel, piping and instrumentation changes, and modification of the control system, was designed and implemented. The new equipment is shown in Figure 1. The new vessel, on the right, is positioned outside the original skid framework in order to achieve the liquid level needed to allow gravity flow from KO#1. New control valves are shown above the vessel. The purpose of this change was to return liquid to the plant condenser using pressure provided by the skid-mounted compressor. The liquid return pump would no longer be used during skid operation – its only function would be to return condensed working fluid to the plant prior to starting the skid. An additional advantage of this new liquid return system is that the skid can now continue normal operation while the liquid was returned to the plant – the old design unloaded the compressor while liquid was returned. As well as increasing the air removal capacity, this also decreased wear on the compressor and eliminated a possible source of air into the system (the high pressure plant air used to unload the compressor).

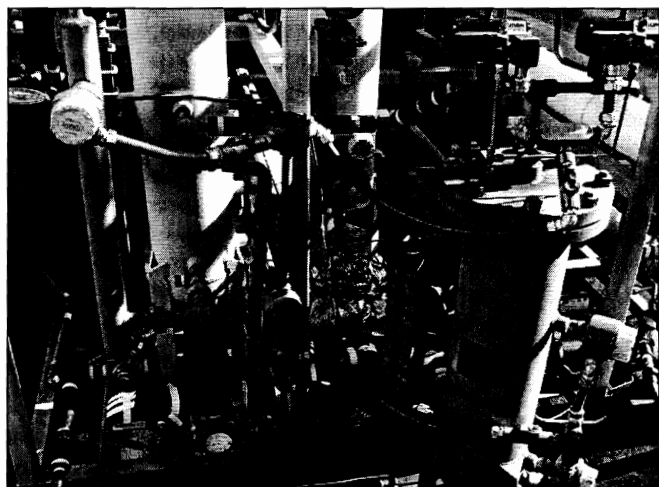


Figure 1. New liquid accumulation vessel and controls.



Figure 2. Additional heat tracing on liquid lines.

In use at Mammoth, water was found in the vessel sumps. Approximately one cup of water (or more) was drained from the unit daily. In cold weather, the unit was observed to shut down due to overfilled KO drums, caused by freezing the control valves. The operator installed additional heat tracing to alleviate this problem. This was done piecemeal, beginning with the most obvious locations where water could accumulate. After the last heat tracing was added (to the second KO drum control valve), the unit operated continually during periods of severe temperature changes, including sub-freezing temperatures at night.

The final modification made to assure continuous operation was an alteration to the line that delivered vapor to the skid. To minimize liquid carryover, a larger line that began with a section sloped back toward the plant liquid accumulator was installed. The effectiveness of this change is not known, as it was made at the same time as the final heat tracing was added.

**Maintenance Issues:** The three years of testing included some maintenance and equipment reliability issues. The compressor was rebuilt after two years. The Mammoth operator indicated that this is unexpected, as they use identical compressors that operate much longer without needing rebuilds. Early operation with frequent compressor unloads is believed to have contributed with compressor wear and may be responsible for premature compressor wear. A liquid level switch failed (for unknown reasons) and was replaced. Finally, the liquid return pump failed. Teardown at Mammoth could find no indication of wear or failure, but the manufacturer examined the pump and stated that it could not be rebuilt at a reasonable cost. It was replaced.

There are still some operational issues with the compressor. It loses oil, and minor amounts of oil have been observed in the system, although not in the piping leading to the membranes. Seal packing has been adjusted – the result of this adjustment on oil consumption is not yet known.

### Performance Evaluation

The Mammoth operators have provided historical operating data for analysis and comparison to data being taken with the NCG skid in operation. This analysis should be complete in the summer of '05 and will be included in the GRC presentation.

### Acknowledgements

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### References

- Mohr, C., G. Mines and K. Bloomfield, "Continual Removal of Non-Condensable Gases for Binary Power Plant Condensers", Geothermal Resources Council Transactions, Vol 25, San Diego CA, August 26-29, 2001.
- Mohr, C., G. Mines and K. Bloomfield, "Continual Removal of Non-Condensable Gases for Binary Power Plant Condensers", Geothermal Resources Council Transactions, Vol 26, Reno, NV, September 2002.
- Mohr, C., G. Mines and K. Bloomfield, "Continual Removal of Non-Condensable Gases for Binary Power Plant Condensers", Geothermal Resources Council Transactions, Vol 28, Indian Wells, CA, August 2004.